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MAST Radioactivity
INDO-PACIFICSHORT REVIEW AND BIBLIOGRAPHY ON
RADIOACTIVITY IN THE INDO-PACIFIC OCEAN

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Purpose

This is one of a series of synopses on the methods and subjects of fisheries biological research, as a contribution by FAO Fisheries Biology Branch to the appraisal of living aquatic resources and of the effects of human activity and of the natural environment on those resources.

This synopsis has been prepared in response to the proposal by the 29th Executive Committee Meeting of the IPFC at Hong Kong, October 1959, that a bibliography and review of existing work and publications concerning radioactivity of marine fish caught in Pacific waters should be prepared.

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CONTENTS

1. NATURAL RADIOACTIVITY OF THE SEA AND ITS BIOTA
(BACKGROUND RADIATION)
2. ARTIFICIAL RADIOACTIVITY OF SEA WATER IN THE INDO-PACIFIC
3. UPTAKE, ACCUMULATION AND LOSS OF RADIOACTIVE SUBSTANCES
BY MARINE BIOSPHERE, WITH DATA ON RADIOACTIVITY IN FISH
IN THE INDO-PACIFIC
 - 3.1 Plankton and benthos
 - 3.2 Fish
4. APPENDIX: Bibliography on radioactivity in the marine
environment in the Indo-Pacific
 - A. Artificial radioactivity in the environment and
biota (mainly surveys in the Pacific)
 - B. Uptake, accumulation and loss of radionuclides by
marine biota (in general, mainly experimental works)
 - C. Effects of radiation on marine life
 - D. General (including methods, bibliographies)

1. Natural radioactivity of the sea and its biota (background radiation)

Natural radioactivity in sea water comes mainly from radiopotassium (K^{40}). The rest of the radioactive elements in sea water (Rb^{87} , U^{238} , Ra^{226} , C^{14} , U^{235} and Th^{232}), contribute slightly more than 10 per cent of the natural radioactivity. (see Table 1). This natural radioactivity of sea water is about 1/10 of the natural radioactivity of graniterocks.

Further contribution to radioactivity in the water comes from cosmic radiation, which, however, is absorbed quickly by the uppermost layers of the sea. Of the ca 35 mrad of the cosmic radiation coming to the surface, only ca 30 per cent reaches a depth of 10 meters and 4 per cent a depth of 50 meters.

The radioactivity of the sea bed varies with the type of sediment. Highest activities are found in deep water sediments: highest in red clay, followed by blue clays and calcareous (e.g. globigerina) oozes. The radioactivity of shallow water sediments, with which commercial marine food resources may come into contact, have considerably lower natural radioactivity than the average soil on land, or about 1/3 of the natural radioactivity of granite rocks.

Marine animals living in the sea also receive, besides the external radiation described above, some radiation from internal sources, mainly from radiopotassium accumulated in the bones. The differences between the radiations received by man on a granite rock at sea level and pelagic (surface dwelling) large fish in the sea (in a depth of ca 20 m), can be demonstrated with the following data (Folsom and Harley 1957, modified)

Man Cosmic rays 35, + granite 90 + internal 17 = 142 mrad/year

Fish Cosmic ray 5 + sea water 1 + internal 28 = 34 mrad/year

2. Artificial radioactivity of sea water in the Indo-Pacific

The present artificial radioactivity in the oceans originates mainly from the fallout of weapon tests. (Seymour, 1959). Shortly after the nuclear weapon test, the immediate fallout in an area of ca 200 to 300 miles from the test seat is considerably greater than the stratospheric fallout further away, but after a few months, up to a

year, these differences are equalled by currents and mixing. In the initial state, the fallout occurs mainly in the surface mixed layer, but a year after the test some artificial radioactivity can be found at a depth of 700 m and more. After release, the amount of radioactivity in the marine environment changes rapidly due to physical decay and also to biological activity. Therefore, the actual amounts reported in the sea water and in fish have only historical value. Some data are given below which serve as examples of the quantities reported. In 1956, some months after the test, the highest value - 19,000 dpm/l - was found between Eniwetok and Ujelang, and the lowest - 48 dpm/l - northeast of Bikini. At present, the fallout has been well distributed over the whole North Pacific Ocean, there being only a little artificial activity in the southern hemisphere.

Of three long-lived fission products - Cs^{137} , Sr^{90} and Ce^{144} - only the last has been found concentrated to some extent in marine organisms. Sr^{90} , if present, occurs at low levels. (Seymour, 1959).

Of non-fission products, radioisotopes of iron, zinc, cobalt and manganese are of importance in the marine biosphere.

According to Hiyama (FAO 1960) in 1958 there was ca 1 μg Sr^{90} /l in the surface waters of the Pacific Ocean and ca 1/10 of this value in other oceans. In the North Pacific the relation between Sr^{90} and Ca was 0.3 μg Sr^{90} /g Ca. The Cs^{137} content of the surface waters of the North Pacific has been estimated between 50 and 150 μg /l. (Folsom 1960)

3. Uptake, accumulation and loss of radioactive substances by marine biosphere, with data on radioactivity in fish in the Indo-Pacific

Marine organisms are taking up elements either directly from the water, or through the food chains. There is also certain absorption and adsorption of substances by the body surface, gills etc. The rate of uptake, accumulation and dissemination of elements depends on the type of organisms and their living and feeding habits, physiology, age of the organisms and on the specific environment where the organisms live. There is also selectivity in the uptake of the elements depending mainly on the physiological function of the element in the organisms.

3.1 Plankton and benthos

Phytoplankton concentrates radioactive elements at a higher rate than other biological groups and therefore a greater number of isotopes

may be taken up by them. Because of the high concentration rate of radioactive isotopes by phytoplankton, it can serve as a general indicator of the levels of introduced radioactivity in the sea. (Seymour et al 1957)

The following examples from literature will illustrate the varying and rapid rate of uptake of radioactive substances by phytoplankton and plankton in general:

Saito and Samashima (1956) found that equilibrium between algae and water was established in 4 hours and after 24 hours about 75 per cent of the radioactivity was found in algae. On the other hand, the removal of the isotopes from the algae was slow. After three weeks, about 70 per cent was removed. Pendleton and Hanson (1958) found that the ecological system as a whole, including inorganic surfaces, removed 95 per cent of the introduced radioactive contamination from the water in 50 hours and 99 per cent in five days.

Donaldson et al (1956) and Seymour et al (1957), found during the surveys of radioactivity in the sea near Bikini, and Eniwetok atolls and the Marshall Islands area long after the weapon tests that the average value of the radioactivity in plankton was about 7,100 and 2,500 times the average value for surface water in the respective areas.

Rice and Willis (1959) found that different species of algae concentrated cerium-144 from 300 to 3,000 times over the amounts in the medium in a period of 30 minutes, and after 24 hours all species had concentrations 2,000 to 4,500 times that of the water. Cerium-144 was also taken up by phytoplankton during 3 days in darkness. Particulate cerium-144 became associated with the algae faster than the ionic cerium. 25 per cent of the cerium-144 was lost in 5 hours when the cells of phytoplankton were suspended in isotope-free sea water. By each cell division half of the cerium 144 content of individual cells was lost in isotope-free water ("biological dilution").

Few data are available on the uptake and accumulation of radioactive isotopes by zooplankton. Borough, Chipman and Rice (1959) report that Artemia reached a steady state in a few hours.

The levels of radioisotopes in plankton vary with time after the release of the isotopes, due to physical decay. Seymour (1959) stated that the fission products (mainly Ce^{144}) contributed 30 per cent of the activity in the plankton in the Pacific and 70 per cent was due to non-

fission radioactive isotopes, mainly Zn^{65} , Co^{57} , 58 , 60 , Fe^{55} and traces of Mn^{54} . Compared with fish, plankton had more radioactive Co and less Fe . Radioactive tungsten (W^{185}) has also been found in plankton.

Borough, Chipman and Rice (1957) found that oysters reached a steady state with radioactive food (containing strontium 89) in 8 days and that the overall concentration factor was ca 2. Concentration of the radioactive elements however varied in different tissues of the shellfish. Soft tissues lost the activity quickly in non-active medium. Different elements however, behaved differently. Cerium 137 in shellfish still increased continuously after 20 days. Chipman, Rice and Price (1959) found that zinc 65 was taken up by shellfish very rapidly and its concentration factor was ca 1,000.

3.2 Fish

Some information on the behaviour of radioactive isotopes in fish is available. Chipman, Rice and Price (1959) found that zinc 65 was rapidly taken up by fish through the digestive tract, to kidney, liver and other organs. Accumulation took place in bone, integument and muscle tissues. When resuspended into nonactive medium there was an immediate loss of most of the radiozinc. However, a small percentage remained with only a very slight loss over periods of many days. Similar conclusions on the loss of radioactive isotopes were made by Borough, Chipman and Rice (1957). They found that most radioactive elements are lost quickly and after 24 hours, less than 10 per cent is left in the fish body, which is usually found in order of decreasing concentration in the alimentary tract, liver, skin, bones and muscles. The percentage of isotopes retained depends on the element, its place of accumulation feeding habits and size of fish. Krumholz, Goldberg and Borough (1957) found that less than 5 per cent of the strontium 90 given with a single feeding to mackerel, was retained in the body after 48 hours. Much of the retained isotope was incorporated in bones. Of the strontium 89 fed to tunas, only 1 to 2 per cent remained in the body after 24 hours.

There is a selective transfer and accumulation of isotopes in different organs of fish, depending on their physiological function. Common elements of tissues and their radioactive isotopes (e.g. radioactive phosphorus) are distributed in all tissues more or less evenly. There also seems to be selectivity in uptake in closely related elements. Borough, Townsley and Hiatt (1956) found that the Sr/Ca ratio in fish is 1:400. This means that marine fish discriminate against strontium. Vertebrate predators however, may also concentrate some elements (e.g. Cs^{137}) to higher levels than found in their prey. (Pendleton and Hanson, 1958)

Seymour (1959) reported that the average values by tissues for beta radioactivity in per cent of total body was as follows:

skin	muscle	bone	liver	viscera
8	1	8	23	60

Donaldson (1959) stated that Zn^{65} usually accounts for 50 per cent or more of the total radioactivity in fish and Fe^{55-59} comprises a major part of the remaining activity. The radioactive isotopes of cobalt account for 7 to 20 per cent of the radioactivity and Mn^{54} 2 to 6 per cent. The carnivorous fish, such as tuna, contained Zn^{65} at the highest level.

A few actual levels of radioactivity in fish in the past could be recorded as examples:

According to Saiki, (FAO 1960) the concentrations of Zn^{65} of highly contaminated fishes in 1954 were as follows: 10^4 uuc/g in liver, kidney and spleen; and 10^2 uuc/g in muscle. One year after previous weapon tests, Welander found Zn^{65} in the order of $10 \mu\text{uuc/g}$, Co^{57-60} 6 uuc/g and Fe^{55} 6 uuc/g from fish collected on reefs in Rongelap Atoll in 1957. Miyama found that in the North Pacific in 1958 there was ca 0.1 uuc Sr^{90} per kg of fish flesh, and 0.3 uuc per kg of whole fish. There was also 0.02 uuc/g of Cs^{137} in edible fish.

Welander (1957) found that the rate of decline was greatest during the first 100 days (90 per cent) of the uptake and that the biological decline of radioactivity was essentially similar in all species. Existing small differences were caused by feeding habits and uptake and retention of shortlived isotopes. Decay in omnivores was more rapid than in carnivores.

The selected data in this article illustrate the fate of artificial radioactivity in the marine environment. As pointed out, the reported actual data have only historical value, because of the various changes taking place. At present the contribution of radioactivity to man through consumption of marine food is relatively minor, compared to the contribution received with terrestrial food. (FAO 1960)

TABLE 1

Radioactive Elements in Sea Water
(from Revelle and Schaefer 1957)

Element	Concentration, mg/kg	Natural activities Conc. $\mu\text{mc.}/\text{liter}$
Potassium	380	330
Carbon	20	0.19
Rubidium	0.2	6.0
Uranium	0.0015	2.7
		0.08
		5.7×10^{-3}
Radium	$0.2-3 \times 10^{-10}$	0.27

4. APPENDIX

Bibliography on radioactivity in the marine environment in the Indo-Pacific

- A. Artificial radioactivity in the environment and
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